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TECHNICAL REPORT BRL-TR-2790

## FIRE RESISTANT EXPLOSIVES

WARREN W. HILLSTROM

MARCH 1987

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US ARMY BALLISTIC RESEARCH LABORATORY  
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19. ABSTRACT (Continue on reverse if necessary and identify by block number) A major problem of explosives is their accidental thermally initiated catastrophic decomposition. Most bulk military explosives, such as RDX, HMX, and TNT have such hazards. Even somewhat safe explosive materials, such as ammonium nitrate, when combined with fuels, such as wax or other hydrocarbons can overheat with catastrophic results.  Additives can make explosives resistant to burning or catastrophic decomposition. Cure-castable, melt-castable, and pressable compositions were made with additives. Several types of flame retardants and other inhibitors were incorporated into these compositions to inhibit the thermal initiatory reactions and yet retain energetic potential when initiated by a strong shock.  Explosive compositions were tested by DSC, Flame Test, Hot Wire Test, Cook Off Test, Plate Dent Test, Drop Weight Impact, as well as compatibility tests. The results indicate that these explosives should be safer in accidents or combat-induced thermal events. (KEYWORDS)					
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## 1. BACKGROUND

Heat has presented hazards for explosives and propellants since they have been known and used. In combat, ammunition is considered particularly vulnerable and consequently, measures are taken to protect it from incendiaries, fuel fires, and other threats. In noncombat situations, many accidental ignitions occur through excessive heating of energetic materials in their manufacture, transport, or storage.

Many catastrophic events have inflicted terrible damage, such as the explosion of 7 million pounds of fertilizer grade ammonium nitrate at Texas City, TX with resultant fatalities of over 560. In this event, two separate shiploads exploded in the harbor after selfheating to the ignition temperature. Another event began with a relatively minor fire on an ammunition train, spread to ordnance items, and resulted in a major disaster at Rossville, GA. The need to prevent such disasters has led to numerous programs aimed at reducing the thermal vulnerability of energetic materials.

Common explosives used by the military are 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), and combinations with inert binders. It would be beneficial to stabilize these materials to prevent thermal initiation of catastrophic decomposition and yet allow them to initiate and perform usefully when exposed to the fully developed detonation wave from a booster explosive.

## 2. THERMAL EFFECTS

It is well known that heat accelerates chemical reactions. Explosives are particularly susceptible to thermally induced decomposition reactions. Many investigators have studied thermal effects on explosives. They have used many different criteria for predicting and measuring stability.

R. N. Rogers determined the critical temperatures of six pure explosives by applying the Frank-Kamenskii equation to them.<sup>1</sup> He defines the critical temperature,  $T_c$ , as the lowest constant surface temperature at which a specific material of a specific size and shape will self-heat catastrophically. 1,3,5-Trisubstituted-2,4,6-trinitrobenzene (TATB) had the highest  $T_c$ . For a one meter diameter sphere it is about 200°C. For comparison, RDX is about 111°C. A smaller RDX sphere, 10 cm diameter, is ca. 150°C. Autocatalysis may cause energetic materials to decompose more rapidly than predicted and/or change the composition of the sample during a test due to accumulation of reaction products.

Wise<sup>2 3</sup> found that the binder in nitramine composite propellants exerts a strong effect on their sensitivity to hot fragments. Initiation was considered to result from conductive ignition. Nitramine-based propellants had significantly higher ignition temperatures than a nitrocellulose-based propellant. The better conductive ignition resistance of some compositions was attributed to lower temperature endothermic decomposition reactions of the

binders. Cosgrove and Owen<sup>4</sup> showed the effects of RDX decomposition products on its decomposition. Nitric oxide retarded the rate of RDX decomposition, but enhanced it over that of an inert gas.

From these references and information from a review<sup>5</sup> important factors affecting thermally induced catastrophic decomposition are: (1) size and shape of the heated material, (2) thermo-chemistry of binder decomposition, (3) chemical effects of nitramine-binder decomposition products, and (4) pressure or degree of confinement. In our program, each of these factors was considered in the selection of additives for particular explosive-binder combinations.

### 3. APPROACH

It should be possible to inhibit or prevent the operation of a catastrophic sequence of thermal reactions in explosives which occur as a result of undesirable thermal sources such as a cook-off, and yet allow the same material to contribute to detonation when the explosive is subjected to a fully developed detonation wave from a booster.

Three routes to prevent runaway decomposition reactions are obvious: (1) develop explosives that resist decomposition, (2) use binders that resist thermal decomposition, and (3) incorporate additives that inhibit or prevent the decomposition reactions. The development of TATB is an example of route (1). However, TATB does have drawbacks such as high cost and relative difficulty of initiation. This task uses routes (2) and (3) to develop new explosive compositions from common explosives with attendant cost and sensitivity similarities but with greatly improved fire resistance.

Thermally stable or stabilized binders were sought with good physical and processibility properties. A review of thermally stable elastomers<sup>6</sup> suggests fluorocarbon elastomers, polyorganophosphazenes, organic heterocyclic elastomers, and silicone elastomers as well as others. However, the presence of large amounts of nitramines in compositions with these polymers severely taxes the ability of the composition to resist ignition. The nitramines also function as oxidizers and contribute to the decomposition of the binder.

Flame retardants are commonly used to prevent the burning of polymers so it is reasonable to use them to increase the fire resistance of explosives also. Usually, fire retardants in solids operate in one or more of the following ways; (1) altering the thermal degradation processes in the solid phase, (2) forming a surface barrier to heat, oxidizer, or fuel, (3) interfering with gaseous oxidation in the vapor space, or (4) absorbing heat through endothermic processes which reduce the amount of heat available for degradation reactions.

Typical actions of flame retardants are, for example, those of phosphorous and halogenated compounds. Phosphorous compounds generate phosphorous acids which can degrade many organic compounds and furnish a syrupy coating on them. These actions tend to create much char and only low amounts of flammable volatiles. Halogenated compounds are considered to act as fire retardants by trapping the free radicals necessary for oxidation reactions in the vapor phase. Antimony compounds act similarly.

The mode of decomposition of RDX itself is not well understood, but flame retardants may be able to interrupt the catastrophic sequence of thermally initiated reactions leading to a detonation. The explosives may still decompose, but in a much less hazardous mode. Interruption of some of the initial free radical reactions may be sufficient to accomplish this.

Explosive compositions were tested by DSC, Flame Test, Hot Wire Test, Cook Off Test, Plate Dent Test, Drop Weight Impact as well as compatibility tests. Equipment and test location were not available for the Taliani or VTS tests. The latter tests were not considered critical to this program since they are designed for long term storage stability rather than the cook off or incendiary threat. They would eventually have to be completed to qualify candidates for Interim Qualification.

#### 4. CALCULATIONS

Preliminary calculations were done using the Kamlet Short Method<sup>7</sup> as adapted by R. McGuire<sup>8</sup> for a programmable hand calculator. They were done on a TI Model 59 hand calculator. In this method, the detonation velocities and detonation peak pressure of CHNO explosives are calculated from the explosive's elemental composition, heat of formation, and initial density in an empirical correlation. The results agree well with predictions from the RUBY and STRETCH BKW computer codes as well as with experimental measurements.

For example, RDX was run using a heat of formation of +14.71 kcal/mol and a density of 1.806 g/cc. The calculated results were  $P_{cj} = 345$  kbars and  $D = 8.81$  km/s. These compare well with  $P_{cj} = 338$  kbars and  $D = 8.70$  km/s experimental.<sup>9</sup>

To simulate explosive compositions with low densities, calculations were made using the plastic bonded explosive (PBX), LX-14, with a composition of 95.5% HMX and 4.5% Estane 5702 and the density varied from 1.83 to 0.472 g/cc. The results are shown in Table 1.

TABLE 1. Detonation Properties for LX-14

DENSITY, g/cc	$P_{cj}$ , kbars	D, km/s
Literature <sup>a</sup>	370	8.83
1.83	340.42	8.72
0.920	86.04	5.57
0.472	22.65	4.16

<sup>a</sup> Ref. 9

Both the detonation pressure and velocity are seen to drop off with increasing porosity. Small amounts of porosity may, however, improve performance through sensitization. This would be a separate consideration not studied here.

Similar calculations were also made for a composition with RDX and a relatively large amount of Estane 5702 to represent a polyurethane foam



binder. It is well characterized<sup>9</sup> with an empirical formula of  $C(5.14)H(7.50)N(0.19)O(1.76)$ ; heat of formation of -95 kcal/mol (-950 cal/g); and density of 1.18 g/cc. A mixture of 71.4% RDX and 28.6% Estane 5702 and a density of 0.637 g/cc gave a heat of formation of -22.5 kcal/mole, detonation pressure of 34.96 kbars and 4.27 km/s. It is not surprising that the results are significantly lower than those given above for neat RDX since this sample has only 26% of the RDX on a density basis. The remainder of the volume is taken up by binder and porosity. The detonation pressure was 10% of the neat RDX value and the detonation velocity is 49% of the neat RDX value.

## 5. EXPERIMENTAL

It was considered necessary that the binder materials be somewhat tough and elastomeric. It would be beneficial if the materials had some resistance to burning in air. The compositions made with the binders should be potentially processable in planetary mixers or melt-cast kettles. Small scale mixes were made in approximately 8 gram batches by hand after compatibility tests were completed. Combinations of these binders were also used.

TABLE 2. Binders

MATERIAL	COMMERCIAL NAME	SUPPLIER
1. Polyurethane Foam	AV 255	Avanti International, Houston, TX
2. " "	XWE 104	" " " "
3. " "	XWE 106	" " " "
4. Acrylic Latex	Hycar 2671	B. F. Goodrich, Cleveland, OH
5. Phosphate Ester-Vinyl Chloride Latex	Geon 650X17	" " " " "
6. " " "	Geon 590X4	" " " " "
7. Cellulose Acetate Buty.	Tenite 264	Eastman Cml Prod., Kingsport, TN
8. " " "	MIL-P-149	JMPTC, APG, MD
9. Vinyl Ester	Derakane 411-45	Dow Cml, Midland, MI
10. " "	Derakane 510N	" " " "
11. " "	Derakane 8084	" " " "
12. Thermoplastic Block Co-polymer	Kraton G1650	Shell Cml Co., Houston, TX
13. " "	Kraton G1652	" " " "
14. Fluorinated Elastomer	Kel F 3700	3M, St. Paul, MN
15. Fire Retardant Coating	Scotchcast 2130	" " " "
16. Plaster of Paris		Bondex Int'l, Toms River, NJ
17. Polyurethane Elastomer	R-45/IPDI	Arco Cml. Co./Thorson Chem. Co.
18. " "	Polyol/N-100	Dow Cml. Co./Mobay Chem. Corp.
19. Polybutene	Indopol H300	Amoco Cml. Corp., Chicago, IL.

Many other potential binder materials were also investigated, but problems with compatibility, processability, or product physical properties eliminated them. Some of the materials considered were (1) numerous epoxies, (2) fluoroelastomers, (3) fluorotelomer dispersions, (4) epichlorohydrin homopolymers, (5) reactive butadiene/acrylonitrile copolymers, (6) polyacrylate elastomers, (7) ethylene-vinylacetate copolymers, (8) polyether based polyurethane, (9) polyester thermoelastic elastomers, and (10) cellulose acetate.

Numerous waxes were also incorporated into compositions to determine processability and product physical properties. Some will be described in following reports.

Plasticizers were used to fluidize some of the above binders at elevated temperatures. They are shown in Table 3.

TABLE 3. Plasticizers

MATERIAL	COMMERCIAL NAME	SUPPLIER
Acetyltriethyl Citrate	Citroflex A-2	Morflex Cml. Co., Greensboro, NC
	Glycerine	
Paraffinic Light Oil	Arcoprime 200	ARCO Petroleum Prods. Co., Phil, PA
Paraffinic Mineral Oil	Tufflo 6016	" " " " " "

Flame retardants and inhibitors have been used for virtually all combustible materials to reduce incidences of fire and thermal damage. However, the situation addressed in this report is somewhat unique in that the explosive contains its own oxidizer in most cases. Thus, the energetic components of the explosive compositions decompose at relatively moderate temperatures and contribute to oxidation of the binder components. To retard these reactions, a flame retardant would have to act in the solid phase. It would also have to be essentially non-reactive with the explosive over the service temperature range.

As a beginning, Lyons<sup>10</sup> records the average requirements for fire-retardant elements to render common polymers self-extinguishing. These are shown in Table 4.

TABLE 4. Average Requirements for Fire-Retardant Elements to Render  
Common Polymers Self-Extinguishing<sup>10</sup>

POLYMER	%P	%Cl	%Br	%P+%Cl	%P+%Br	%Sb <sub>4</sub> O <sub>6</sub> + %Cl	%Sb <sub>4</sub> O <sub>6</sub> + %Br
Cellulose	2.5-3.5	>24			1+9	12-15+9-12	
Polyolefins	5	40	20	2.5+9	0.5+7	5+8	3+6
PVC	2-4	40		NA		5-15%Sb <sub>4</sub> O <sub>6</sub>	
Acrylates	5	20	16	2+4	1+3		7+5
Polyacrylo-							
nitrile	5	10-15	10-12	1-2+10-12	1-2+5-10	2+8	2+6
Styrene		10-15	4-5	0.5+5	0.2+3	7+7-8	7+7-8
Acrylonitrile-							
butadiene-							
styrene		23	3			5+7	
Urethane	1.5	18-20	12-14	1+10-15	0.5+4-7	4+4	2.5+2.5
Polyester	5	25	12-15	1+15-20	2+6	2+16-18	2+8-9
Nylon	3.5	3.5-7				10+6	
Epoxyes	5-6	26-30	13-15	2+6	2+5		3+5
Phenolics	6	16					

Specific commercial materials used in these tests are listed in Table 5.

NOTE: Combinations of fire-retardant elements are shown as ranges in some case, e.g., the amounts of Sb<sub>4</sub>O<sub>6</sub> and Cl in nitrocellulose are 12-15% of Sb<sub>4</sub>O<sub>6</sub> with 9-12% of Cl. The percentages are all weight percents.

It can be seen from this table that the required amounts of retardants to render the polymers self-extinguishing may vary widely for each material. For example, polyurethane only needs 1.5% of phosphorus, but 18-20% of chlorine is needed for the same effect. Synergistic effects are also shown.

TABLE 5. Flame Retardants And Inhibitors

MATERIAL	COMMERCIAL NAME	SUPPLIER
Zinc Borate	Firebrake 2B	U.S. Borax, Montvale, NJ
Hexabromobiphenyl	Firemaster BP-6	Michigan Chemical, Chicago, IL
Nolybdenum Flame Suppressant	Kemgard 425	Sherwin Williams Co, Cleveland, OH
"	" 911A	" " " " "
"	" 981	" " " " "
Triaryl Phosphate Ester	Kronitex 50	FMC Corp., King of Prussia, PA
Calcium Formate	Calcium Formate	Int'l Minerals & Chemicals Mundelein, IL
Antimony Oxide	Antimony Oxide	
Ammonium Phosphate	Ammonium Phosphate	J. T. Baker, Phillipsburg, NJ
Aluminum Oxide Hydrate	ATH	Solem Industries, Norcross, GA
Organo Phosphorous Diol C-206		FMC Corp., Philadelphia, PA
Halogenated cyclohexane	FR-651-P	Dow Chemical, Midland, MI.
Brominated polyol	XFS 43357.00	" " " "

## 6. THERMAL TEST RESULTS

Numerous compositions were made with RDX, HMX, TATB, binders, plasticizers, and additives. The compositions were tested for resistance to thermal damage and for explosive performance.

6.1 Hot Wire Tests. The Hot Wire Test was developed to simulate hot particle heating of the explosive compositions. The apparatus is shown in Figure 1. Samples were 1 cm cubes, or slightly smaller, and weighed ca. 1 gm. Bomb calorimeter fuse wire, 0.152 mm diam., was inserted into the sample by means of an incision. The wire was electrically heated by means of a set voltage to bright orange color. The time elapsed until appearance of a flame or the wire breaks was recorded. Representative results of hot wire tests are shown in Table 6.

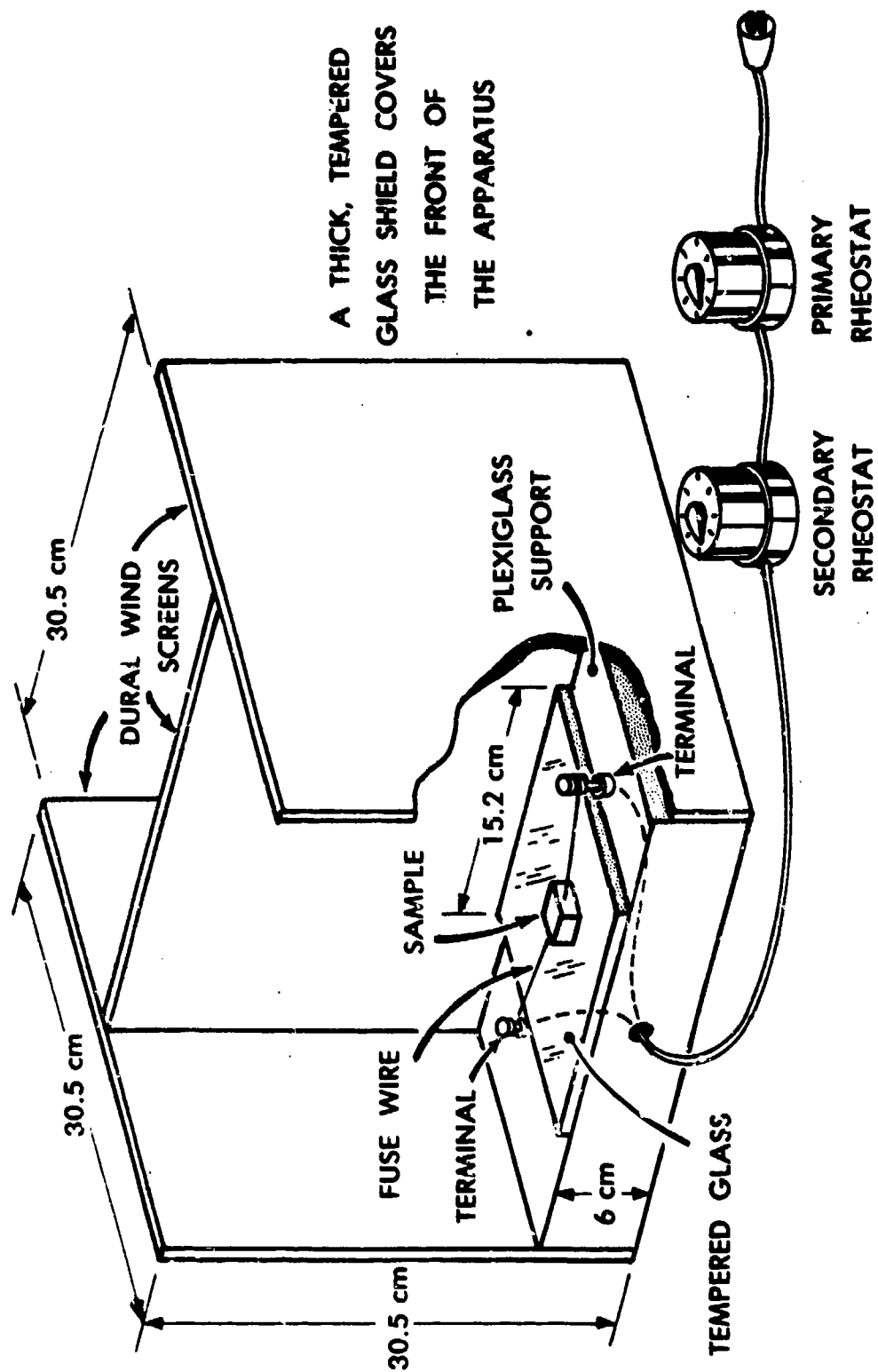


Figure 1. Hot Wire Ignition Test Apparatus.

TABLE 6. Hot Wire Test Results

	Binder Material	% RDX	Additive Type	%	T sec	Comments
1.	Polyurethane Foam	71	none	na	3.2	Burn to Black Ash
2.	" "	50	Kemgard 425	10	4.0	" " " "
3.	" "	50	" 911A	10	3.1	" " " "
4.	" "	50	" 981	10	3.7	" " " "
5.	" "	50	Kronitex 50	10	14.6	" " Brown Oily R.
6.	" "	50	"	10	13.0	" " Black Ash
7.	" "	50	"	20	>60	No flame
8.	" "	50	Calcium Formate	10	3.2	Burn to Black Ash
9.	" "	50	Antimony Oxide	10	4.9	" " " "
10.	" "	50	Firemaster	10	3.8	" " " "
11.	CAB MIL SPEC	85	Firebrake ZB	9	6.3	" " " "
12.	CAB Tenite	70			14.3	Wire Breaks
13.	CAB MIL SPEC	56	Firebrake ZB	20	>30	Smoking Decomp.
14.	Polyurethane Foam	45	Antimony Oxide + Firemaster	18	7.2	Breaks Wire
15.	Geon 650x17	71	None		>30	Smokes to Black Ash
16.	Polyurethane Foam	62	Geon 650x17	31	13.4	Burns " " "
17.	" "	71	" 650x17	21	10.5	Breaks Wire
18.	" "	71	" 590x4	21	18.3	" "
19.	PU Foam XWE104	57	None		10.3	Burns to Black Tar
20.	" " "	67	"		8.5	" " " "
21.	" " XWE106	57	"		2.4	" " " Ash
22.	" " "	67	"		2.7	" " " "
23.	Scotchcast 2130	50	"		7.9	" " " "
24.	Polyurethane Foam	50	FMC C-206	10	13.0	" " " "
25.	Plaster of Paris	41	Hycar 2671	18	25.0	" " Brown "
26.	" " "	60	" "	14	8.3	" " " "
27.	Hycar 2671	81	None		10.6	Wire Breaks
28.	Kraton G1650	85	Firebrake ZB	9	24.3	Green Flame
29.	" G1652	63	"	14	38.0	Burns or Decomposes
30.	Derakane 510N	80	None		16.4	Wire Breaks
31.	Kraton 1652	59	Ammonium Phos.	16	>160	Smokes & Decomposes

TABLE 6. Hot Wire Test Results (Continued)

	Binder Material	% RDX	Additive		T sec	Comments
			Type	%		
32.	KF 3700	67	None		6.5	Wire Breaks
33.	Polyurethane Foam	80	Hycar 2671	14	6.5	Burns to Black Ash
34.	PU (E4000)	HMX75	None		8.3	Flame
35.	" (E4500)	HMX73	"		9.8	Flame
36.	" (E4500)	HMX65	K50	10	33.1	Melts & burns to tar
37.	PU (E4500)	RDX65	Ammon. Phosphate	10	74.4	Smoke then flame
38.	Derakane 510N	TATB73	None		>600	Sl. charring
39.	" 8084	HMX73	"		7.6	Burns to black ash
40.	" "	RDX73	"		5.8	" " " "
41.	" "	TATB73	"		>480	Sl. charring
42.	Kraton & Arco	RDX65	Ammon. Phosphate	10	>400	No flame
43.	PB & oils	RDX77	Amm. Phos.- K50	15	150	Smoke to black ash
44.	" "	RDX82	" "	10	150	" " " "
45.	Paraffin wax	RDX91	None		150	Some smoke, no ash
46.	Poyurethane foam	RDX50	FR651P (Dow)	10	25	Some burn, some smoke
47.	" "	"	XFS 43357.00	10	11	Burn
48.	PB & FE wax	RDX90	K50	6	80	"

6.2 Molten Explosive Ignition. Several basic explosives were also heated in the hot wire test, but they melted and flowed away from the wire without effect. The test was modified somewhat to study their ignition. A small groove was sawed in the rim of a small ceramic cup (4.2 mm ID, 5.0 mm IH) used for Differential Thermal Analysis. A loop of the fuse wire was coiled once and lowered into the cup by way of the groove. TNT was tried first. It melted easily and formed a pool in the bottom of the cup. The coil of wire dipped into the liquid. Heavy black smoke was given off prior to ignition which occurred after approximately 2 minutes. It was not determined whether the ignitions occurred in the vapor or liquid phases.

Since most of the explosive compositions tested in this report contained RDX, a compressed sample (30 mg) of neat, Class 1, Grade B RDX was also tested with the hot wire in the ceramic cup. It did not ignite after heating for periods of up to 3 minutes. It melted to give a clear, pale yellow liquid. During the heating there were occasional bubbles and light smoking. The test was repeated several times with the same results. The temperature of the molten RDX was followed by a thermocouple inserted in the cup, but a somewhat high temperature was recorded which may have been due to the close proximity of

the resistance wire heat source. Another experiment was done to more accurately measure the temperature. In this a 50 mg sample of RDX was heated in a small cavity drilled in a 1" thick block of steel laid on top of a hot plate. A nearby small cavity in the block held an iron-constantan thermocouple. After 16 minutes heating on high heat, the RDX started melting with the block temperature being 204 C (corrected). This corresponds with literature values. After 18 minutes the block temperature had risen to 213 C and the molten RDX was bubbling and yellowing. After 19 minutes the temperature was 218 C and the RDX began to violently bubble and smoke. A metal spatula was immersed in the effluent smoke, but no decomposition products or sublimed material condensed. After 25 minutes the temperature was 244 C and all of the RDX was gone.

Another interesting explosive, Detasheet, PETN in a flexible binder and sold by DuPont, was also heated in the above described ceramic cup. In four tests with 0.095 g each, the material quickly melted and boiled until ignition at 41 seconds.

6.3 LSC and Flame Tests. A very simple test, the Flame Test, consisted of bringing a match flame directly under a small sample of the material. It is a severe test, but seems to give a clear go-no-go distinction. No explosives passed the test entirely satisfactory. The results of Flame Tests and DSC measurements on the same compositions are shown in Table 7.



TABLE 7. DSC AND FLAME TEST RESULTS

Binder Material	%		Additive Type	%	DSC	DSC	Flame Test
	RDX				Onset, C	Peak, C	
1. Polyurethane Foam	71		none	na	194	229	B
2. " "	50		Kemgard 425	10	192	230	B
3. " "	50		" 911A	10	192	228	B
4. " "	50		" 981	10	197	225	B
5. " "	50		" 50	10	189	219	B*
6. " "	50		"	10	187	228	-
7. " "	50		"	20	193	229	B*
8. " "	50		Calcium Formate	10	190	227	B
9. " "	50		Antimony Oxide	10	198	231	B
10. " "	50		Firemaster	10	-	-	B
11. CAB MIL SPEC	85		Firebrake ZB	9	-	-	B
12. " Tenite	70				197	247	B
13. " MIL SPEC	56		Firebrake ZB	20	204	242	B
14. Polyurethane Foam	45		Antimony Oxide + Firemaster	18	198	230	-
15. Geon 650x17	71		None		-	-	-
16. Polyurethane Foam	62		Geon 650x17	31	204	232	B
17. " "	71		" 650x17	21	204	227	B
18. " "	71		" 590x4	21	204	236	B
19. PU Foam XWE104	57		None		193	228	B
20. " " "	67		"		193	228	B
21. " " XWE106	57		"		-	-	-
22. " " "	67		"		-	-	-
23. Scotchcast 2130	50		"		194	230	B
24. Polyurethane Foam	50		FMC C-206	10	179	222	B
25. Plaster of Paris	41		Hycar 2671	18	206	237	B*
26. " " "	60		" "	14	206	242	B*
27. Hycar 2671	81		None		205	238	B
28. Kraton G1650	85		Firebrake ZB	9	204	239	B
29. " G1652	63		"	14	204	245	-
30. Derakane 510N	80		None		205	248	B
31. Kraton 1652	59		Ammonium Phos.	16	197	244	B
32. KF 3700	67		None		205	240	B

33. Polyurethane Foam	80	Hycar 2671	14	205	235	-
34. PU (E4000)	HMX75	None				B
35. PU (E4500)	HMX73	None				B
36. PU (E4500)	HMX65	K50	10			B
37. PU (E4500)	RDX65	Ammon. Phosphate	10			B
38. Derakane 510N	TATB73	None		312	327	B*
39. Derakane 8084	HMX73	None		239	280	B
40. " "	RDX73	None		208	230	B
41. " "	TATB73	None		312	335	B*
42. Kraton & Arco	RDX65	Ammon. Phosphate	10	185	230	B
43. PB & cils	RDX77	Amm. Phos. +K50	15	173	232	B
44. " "	RDX82	" " " "		-	-	-
45. Paraffin wax	RDX91	None		204	238	B
46. PolyurethaneFoam	RDX50	Dow FR651P	10	190	229	B
47. " "	RDX50	XFS 43357.00	10	204	223	B
48. PB & PE wax	RDX90	K50	6	204	232	B

B = burns

B\* = burns after several passes of the flame

- = no test done

6.4 Cook Off Test. Cook-Off Tests were done to assess the resistance of several compositions to catastrophic thermal decomposition. The test apparatus is shown in Figure 2. The explosive billets, 6.35 cm D x 15.2cm L, were cast into 1.27cm wall thickness steel cylinders and heated electrically until cylinder failure. A thermocouple records the temperature at the explosive-wall interface. When Comp B was heated in this completely filled apparatus at 1.28° C/sec, the temperature at the explosive-wall interface jumped when it arrived at 176° C after 137 seconds. The result was a violent reaction, but not considered a detonation.

A composition with 60% RDX, 14% acrylic rubber, and 26% Plaster of Paris was heated in this same test. The temperature rose slowly until it reached 158.4° C at 187 seconds. At this point it jumped and returned to the baseline overall heating rate was 0.85° C/sec. The cylinder was recovered intact although the bolts holding the end plates onto the cylinder failed. No explosive was recovered. The plaster may have been absorbing more energy than the Comp B during the heatup. It decomposes endothermically in the vicinity of 150° C and releases water. The steam produced would pressurize the sealed chamber leading to failure of the item. These mild results are much to be preferred over detonations or violent reactions such as resulted with Comp B.

Another composition with 80 % RDX and 20 % brominated vinyl ester binder was heated in this same test. In this case a violent reaction occurred at 197° C after 180 seconds giving an overall heating rate of 0.96° C/sec. The vinyl ester composition heated up slower than Comp B with reaction occurring 21° C higher in temperature. The degree of violence of reaction was similar to that of Comp B.

Another composition with 65% RDX, 10% ammonium phosphate, and a Kraton-Arcoprime binder, was heated in this test. It was heated somewhat slower (0.522° C/sec.) A very mild reaction occurred after 381 seconds at 199° C.

## 7. PERFORMANCE TESTS

Several promising compositions were cast or pressed into steel cylinders for plate dent tests to measure relative performance. The cylinders have a 4.83 cm ID and 5.08 cm L. The dent is made in a 7.62 cm thick plate of RHA steel. A booster of 5.08 cm D and 2.54 cm L Comp B was used to insure initiation. The results are shown in Table 8.

## COOK-OFF BOMB CROSS SECTION

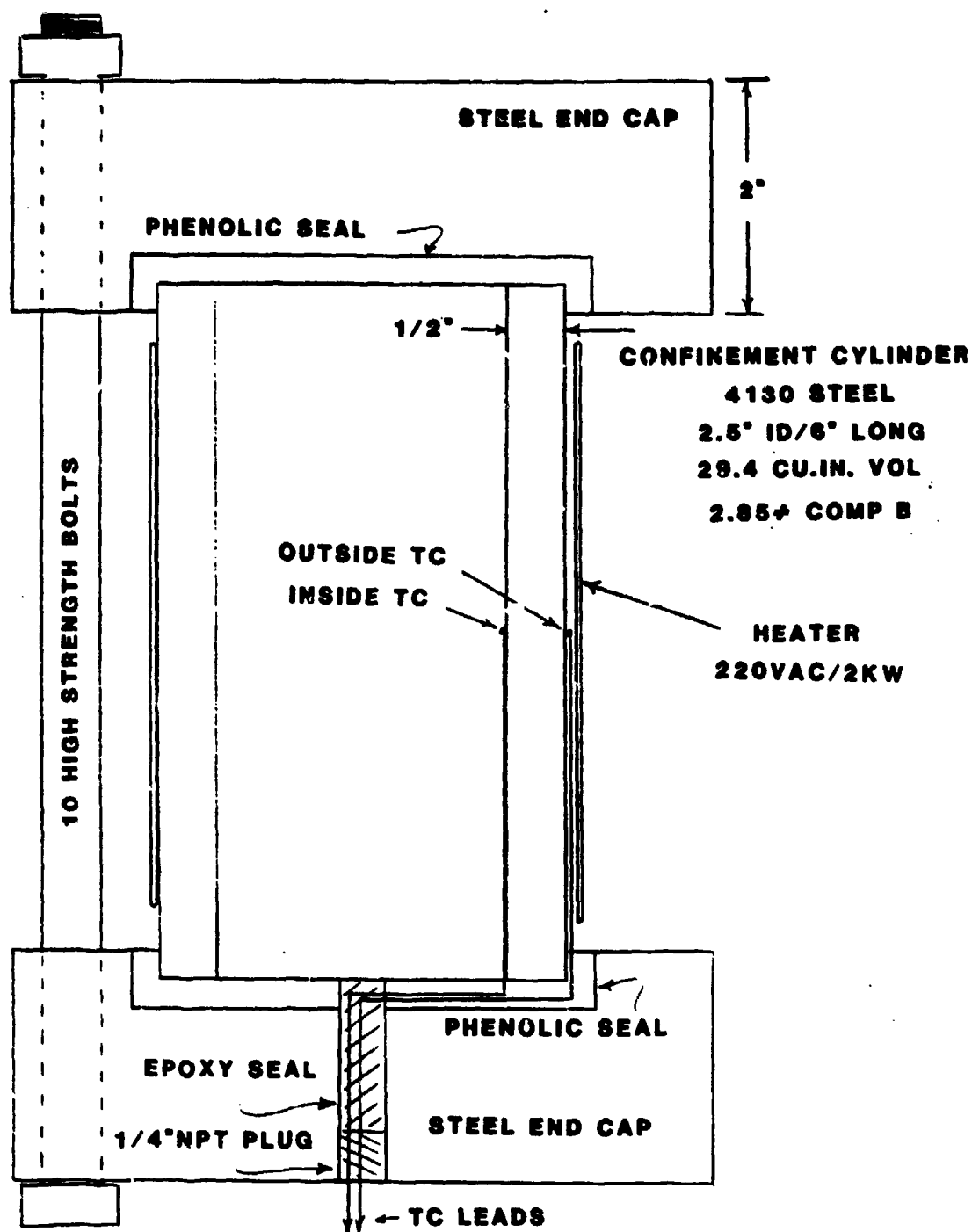


Figure 2. Cook-Off Test Apparatus.

TABLE 8. Plate Dent Test Results

Round No.	a Explosive		RDX		b	
	Composition	Mass, g	Density, g/cc	Density, g/cc	RDX, g	Dent, mm
1.	TNT		1.600		(147)	7.95
2.	Comp B		1.710		(157)	9.92
3.	Inert Wax					0.78
4.	Mix # 6	48	0.778	0.389	24	2.28
5.	Mix # 7	80	0.870	0.487	40	3.66
6.	Mix # 33	72	1.100	0.883	58	4.03
7.	Mix # 26	102	1.100	0.656	61	3.85
8.	Mix # 29	128	1.390	0.877	81	6.13
9.	Mix # 38	147	1.590	1.161	107	6.30
10.	Mix # 34	139	1.500	1.125	104	7.93
11.	Mix # 30	145	1.560	1.248	116	8.14
12.	Mix # 28	139	1.510	1.285	118	8.62
13.	LX-14	168	1.810	1.728	160	10.75

a. Mix numbers refer to Tables 6 & 7.

b. Total energetic amounts, RDX, TNT, HMX, or TATB.

The dent depths are seen to depend on the amounts of energetic component present in the cylinder. The low values for explosive masses and densities for many of the mixes indicate the presence of voids and/or porosity in many of the finished items. The amounts of additives in the mixes are 10, 20, 14, 14, 14, 20 (retardant binder), 0, 20 (retardant binder), and 9 wt.%, respectively. These amounts seem to be effective to deter thermal ignition from Hot Wire Tests, but also affect performance by reducing the amount of energetic material in the mixes.

A plot of dent depth vs total energetic amount is shown in Figure 3. Slightly deficient performance can be seen for TNT and also somewhat for Comp B, but this is reasonable when the relative energetic strengths of RDX and TNT are compared.

## 8. CONCLUSIONS

The use of inhibitors in explosive compositions reduces their ignitability by the Hot Wire Test and Cook Off Test. These materials should be safer in combat-induced thermal events. Performance, however, is somewhat reduced since the amount of energetic component has been reduced by substitution of additive and the preparations were made using less than optimum conditions. Further work is planned to improve processing equipment and procedures, to investigate the mechanism by which the additives operate, and to continue Cook-Off tests.

# PLATE DENT TESTS

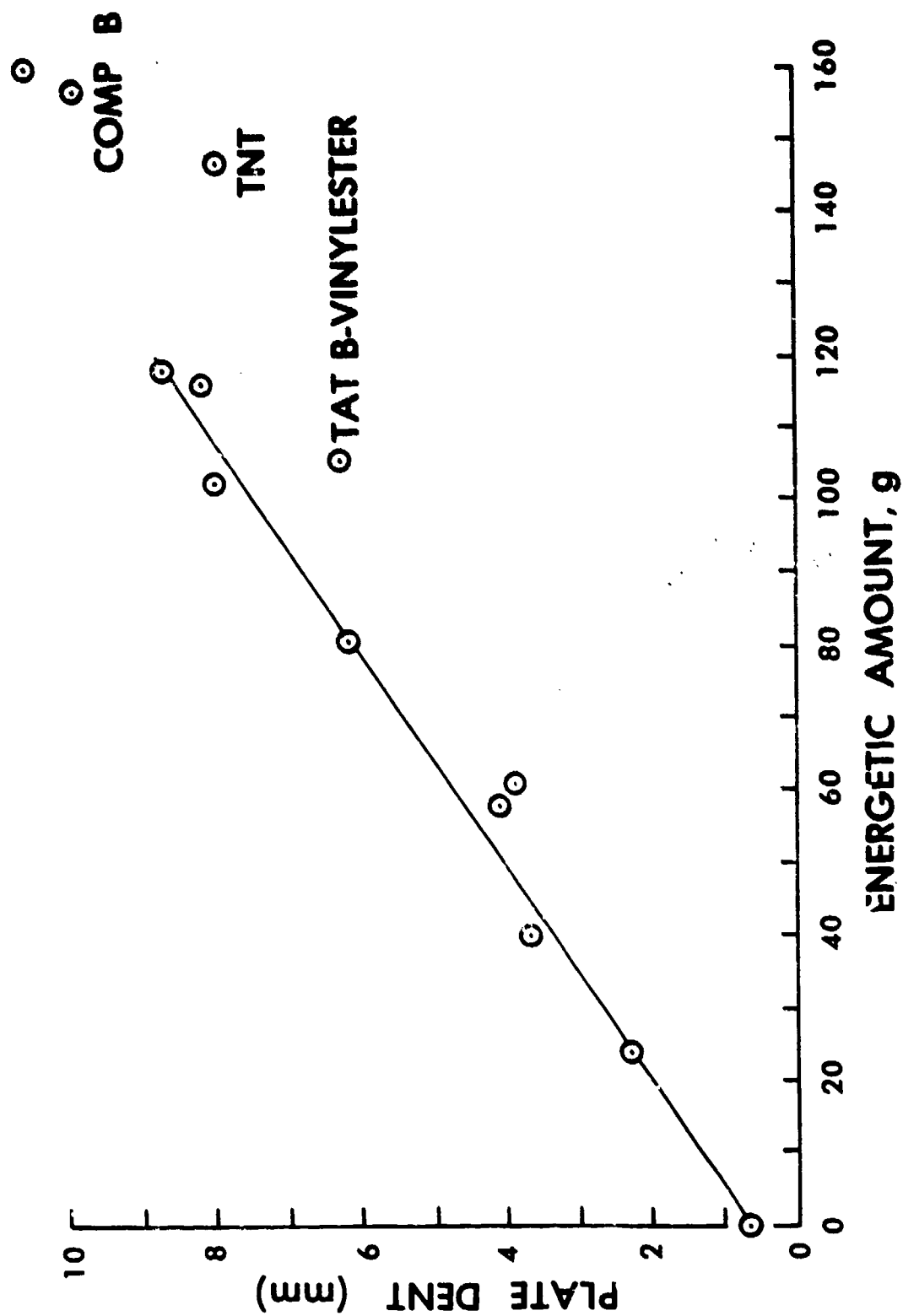


Figure 3. Plate Dent Test Results

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